VIII. 17. Differences in Muscle Activities during Shoulder Elevation in Patients with Symptomatic and Asymptomatic Rotator Cuff Tears: Analysis Using Positron Emission Tomography

Shinozaki N.¹, Sano H.¹, Omi R.¹, Kishimoto K.¹, Watanuki S.², Tashiro M.², and Itoi E.¹

¹Department of Orthopaedic Surgery, Tohoku University School of Medicine
²Cyclotron Radioisotope Center, Tohoku University

Introduction

Shoulder pain is a common symptom of patients with rotator cuff tears, which may need to be surgically repaired if the conservative treatment does not work. On the other hand, a considerable number of people are found to have rotator cuff tears without pain in general population¹-³. However, differences between patients with symptomatic and asymptomatic rotator cuff tears have not yet been fully clarified.

Recently, muscle activities during exercise were successfully evaluated by positron emission tomography (PET) using fluorodeoxyglucose (FDG). PET is a nuclear medicine tool for quantification of regional blood flow and tissue glucose metabolism in vivo. Once ¹⁸F-FDG is taken up by the muscle cells, it remains in the cells as FDG-6-phosphate after phosphorylation; therefore, ¹⁸F-FDG accumulation in the muscle can be used as a parameter of glucose intake by the muscle or the muscle activity.

Nowadays, FDG-PET is widely used for the assessment of skeletal muscle activities, especially in the area of sports medicine⁴-⁶. However, application of FDG-PET to shoulder muscles remains sparse⁷,⁸. Omi et al. established the standardized experimental protocol for shoulder scaption exercise for FDG-PET measurement⁸.

We hypothesized that muscle activity patterns during arm elevation were different in patients with symptomatic and asymptomatic rotator cuff tears. The purpose of the present study was to compare the muscle activities detected by FDG-PET during shoulder scaption exercise between patients with symptomatic and asymptomatic rotator cuff tears.
Materials and Methods

The experimental protocol of the present study was approved by the Institutional Ethics Committee, and a signed consent form was obtained from each patient prior to FDG-PET examination.

Subjects

Subjects evaluated in the present study were divided into three groups (asymptomatic, symptomatic, and control). Twelve shoulders in 11 patients (five males and six females) with full-thickness rotator cuff tears were included in the present study. The average age of the patients was 69 years. In all patients, the presence of a full-thickness rotator cuff tear was confirmed by magnetic resonance imaging (MRI). To standardize patient conditions, we included rotator cuff tears involving the supraspinatus alone or involving the supraspinatus and the infraspinatus. The tear size was categorized with its longest diameter as small (<1 cm) for two patients, medium (1–3 cm) for eight patients, and large (3–5 cm) for two patients. Patients who had partial-thickness or massive rotator cuff tears (>5 cm) were excluded. Patients with any history of shoulder surgery, metabolic disease, or diabetes mellitus were also excluded.

To divide patients with rotator cuff tears into symptomatic and asymptomatic groups, patients were asked to grade the pain at rest as well as at movement on a numerical rating scale (0-10). When the highest pain score in these scores was equal to or less than 1, the rotator cuff tear was defined as asymptomatic. When the highest pain score in these scores was greater than 3, the rotator cuff tear was defined as symptomatic. In the control group, six shoulders of six healthy, age-matched volunteers were analyzed (three males and three females, average age, 73.8).

Experimental protocol

Experimental protocols for both shoulder scaption exercise and FDG-PET examination were previously established by Omi et al.8) FDG was injected after scaption exercise of bilateral arms (200 repetitions in 10 minutes) in the scapular plane using a weight of 0.25 kg (Steel Band; Tiger Medical Instruments, Osaka, Japan), which was fixed to the wrists. After FDG injection, the subjects were asked to repeat the same exercise (Fig. 1).
**PET examination**

Using a PET scanner (SET-2400W; Shimadzu Inc., Kyoto, Japan) with an intrinsic spatial resolution of 3.9 mm full width at half maximum, a set of emission scans in the three-dimensional data acquisition mode was obtained from the base of the neck to the middle of the upper arm 50 min after FDG injection. The axial field of the view of this scanner was 200 mm, and images were obtained by performing two incremental scans, which took 8 min each. Using a $^{68}$Ge/$^{68}$Ga external rotating line source, transmission scans (lasted 5 min each) were obtained after the emission scans (post-injection transmission) to correct tissue attenuation. All data were corrected for dead time, decay, and measured photon attenuation. They were reconstructed into a 128×128×63 matrix for a set of three-dimensional volume images using Fourier rebinning$^9$ and the ordered subset Expectation–Maximization$^{10}$ algorithm with the aid of a supercomputer SX-7 at the Information Synergy Center, Tohoku University.

**MRI examination**

MRI was performed on both shoulders of all subjects for the purpose of image fusion using the FSE-XL Sequence (Signa Horizon LX 1.5T Ver.9.1; GE Healthcare, Milwaukee, Wisconsin, USA). Measurement conditions were as follows: repetition time/echo time was 3000/85 ms, number of excitations was one, field of view was 46 cm, number of matrices was 512×512, slice thickness was 3 mm, and slice gap was 1.5 mm.

**Image analyses**

The PET images were fused with MR images at the same level using a specialized software Dr. View/LINUX (AJS Inc., Tokyo, Japan), which enabled us to delineate the contour of each muscle (Fig. 3). Subsequently, the volume of interest (VOI) was placed on the MR image for each shoulder muscle.

Then, SUV was calculated to quantify the activities for each VOI using the following equation:

$$\text{SUV} = \frac{\text{mean VOI count (cps/g)} \times \text{body weight (g)}}{\text{injected dose (MBq)} \times \text{calibration factor (cps/MBq)}}$$

SUV is the ratio of the amount of FDG accumulated in a certain VOI compared to the situation, where FDG is distributed equally over the whole body.
Statistical analyses

One-way factorial analysis of variance followed by the Tukey’s multiple comparison test was employed for multiple comparisons of SUVs in each portion of the shoulder muscle between the three groups. \(P<0.05\) was considered statistically significant.

Results

The PET/MRI fusion image in the coronal plane clearly exhibited an increased uptake of FDG in the trapezius of the symptomatic group. Interestingly, the uptake was rather decreased in the deltoid of the symptomatic group compared to the asymptomatic group (Fig. 4). In the axial plane, uptakes of FDG both in the trapezius and the levator scapulae were greater in the symptomatic group than in the asymptomatic group (Fig. 5).

SUV of the middle deltoid in the symptomatic group was significantly lower than that in the asymptomatic or control group (Table 1). The average SUVs of rotator cuff muscles are shown in Table 2. SUV of the supraspinatus in the symptomatic group was significantly lower than that in the control group. On the other hand, SUVs of other rotator cuff muscles did not show any significant differences among the three groups, although the symptomatic group represented lower muscle activities than the other two groups (Table 2).

The average SUVs of the scapular muscles are shown in Table 3. In comparison among the scapular muscles, SUV of the superior portion of trapezius was significantly higher in the symptomatic group than the other two groups (Table 3). In the levator scapulae, SUV was significantly higher in the symptomatic group than in the asymptomatic group (Table 3).

Discussion

Results of the present study clearly demonstrated that the middle deltoid activities were significantly lower in the symptomatic group than in the other groups. The supraspinatus activities were significantly lower in the symptomatic group than in the control group. The scapular muscle activities were significantly higher in the symptomatic group than in the other groups.

A consensus exists that the deltoid is the most important elevator of the arm in the scapular plane\(^{11}\). Several asymptomatic simulation studies were conducted to clarify the cause of decreasing deltoid activity. Itoi et al. reported that abduction strength was significantly increased after pain block\(^{12}\). Recently, Cordasco et al. supported that subacromial injection of local anesthetics improved the deltoid firing in patients with
symptomatic rotator cuff tears\textsuperscript{13}). Furthermore, Scibek et al. reported that glenohumeral elevation increased significantly with decreasing scapular upward rotation after pain block\textsuperscript{14}). On the basis of these previous studies, we assumed that the decreased deltoid activity observed in symptomatic patients might be substituted by the increased activities of the superior trapezius and levator scapulae.

In conclusion, the muscle activity pattern during shoulder scaption differed between rotator-cuff-tear patients with and without symptoms. Dysfunction of the rotator cuff muscles caused by tendon tearing seemed to be compensated by the deltoid in asymptomatic patients and by the scapular muscles in symptomatic patients.

References


Table 1. SUV in each portion of the deltoid.

<table>
<thead>
<tr>
<th>Deltoid</th>
<th>symptomatic</th>
<th>asymptomatic</th>
<th>control</th>
<th>ANOVA p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>anterior</td>
<td>0.885± 0.151</td>
<td>1.425 ± 0.551</td>
<td>1.306 ± 0.362</td>
<td>0.071</td>
</tr>
<tr>
<td>middle</td>
<td>1.378 ± 0.494</td>
<td>2.413 ± 0.273</td>
<td>2.196 ± 0.540</td>
<td>0.0030</td>
</tr>
<tr>
<td>posterior</td>
<td>1.108 ± 0.201</td>
<td>1.462 ± 0.341</td>
<td>1.397 ± 0.155</td>
<td>0.0546</td>
</tr>
</tbody>
</table>

Values are the mean ± SD. *a : p < 0.01, *b : p < 0.05 When ANOVA resulted in significance at 95%, the Tukey HSD post-hoc test was applied.

Table 2. SUV of the cuff muscles.

<table>
<thead>
<tr>
<th>Cuff muscle</th>
<th>symptomatic</th>
<th>asymptomatic</th>
<th>control</th>
<th>ANOVA p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supraspinatus</td>
<td>1.738 ± 0.456*</td>
<td>1.895 ± 0.426</td>
<td>2.479 ± 0.542*</td>
<td>0.0402</td>
</tr>
<tr>
<td>Subscapularis</td>
<td>1.792 ± 0.228</td>
<td>2.589 ± 1.118</td>
<td>2.411 ± 0.502</td>
<td>0.167</td>
</tr>
<tr>
<td>superior</td>
<td>1.360 ± 0.166</td>
<td>2.030 ± 0.933</td>
<td>1.888 ± 0.442</td>
<td>0.163</td>
</tr>
<tr>
<td>middle</td>
<td>1.262±0.148</td>
<td>1.528 ± 0.434</td>
<td>1.502 ± 0.190</td>
<td>0.239</td>
</tr>
<tr>
<td>Inferaspinatus</td>
<td>1.105 ± 0.240</td>
<td>1.348 ± 0.398</td>
<td>1.426 ± 0.266</td>
<td>0.206</td>
</tr>
<tr>
<td>superior</td>
<td>0.924 ± 0.188</td>
<td>1.260 ± 0.475</td>
<td>1.151 ± 0.231</td>
<td>0.218</td>
</tr>
<tr>
<td>Teres minor</td>
<td>1.194 ± 0.125</td>
<td>1.338 ± 0.298</td>
<td>1.352 ± 0.150</td>
<td>0.364</td>
</tr>
</tbody>
</table>

Values are the mean ± SD. *b : p < 0.05 When ANOVA resulted in significance at 95%, the Tukey HSD post-hoc test was applied.
Table 3. SUV in the scapular muscles.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>symptomatic</th>
<th>asymptomatic</th>
<th>control</th>
<th>ANOVA p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T± SD</td>
<td>T± SD</td>
<td>T± SD</td>
<td></td>
</tr>
<tr>
<td>Trapezius</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>superior</td>
<td>1.615 ± 0.441</td>
<td>0.791 ± 0.331</td>
<td>1.019 ± 0.129</td>
<td>0.0016</td>
</tr>
<tr>
<td>inferior</td>
<td>1.011 ± 0.135</td>
<td>0.784 ± 0.176</td>
<td>0.867 ± 0.154</td>
<td>0.0665</td>
</tr>
<tr>
<td>Levator scapulae</td>
<td>1.449 ± 0.290</td>
<td>0.988 ± 0.235</td>
<td>1.211 ± 0.192</td>
<td>0.0168</td>
</tr>
<tr>
<td>Rhomboids</td>
<td>1.181 ± 0.132</td>
<td>0.979 ± 0.153</td>
<td>1.064 ± 0.122</td>
<td>0.0645</td>
</tr>
<tr>
<td>Serratus anterior</td>
<td>1.259 ± 0.172</td>
<td>1.602 ± 0.463</td>
<td>1.406 ± 0.171</td>
<td>0.177</td>
</tr>
</tbody>
</table>

Values are the mean ± SD. *a : p < 0.01, *b : p < 0.05. When ANOVA resulted in significance at 95%, the Tukey HSD post-hoc test was applied.

Figure 1. PET examination protocol. Scaption exercises were performed for 10 min before and after FDG injection. PET scanning was initiated 50 min after FDG injection.

Figure 2. Photographs of scaption exercise. The scapular plane was defined as a plane that inclines 30º anteriorly from the coronal plane. The exercise consisted of 200 repetitions of elevation in the scapular plane from 0 to 90º with weights of 0.25 kg tied around the wrists. The exercise was performed at a constant speed of 90º/s.
Figure 3. The MR image of axial view (a), the PET image at the same plane as the MR image (b), and the MR image fused to the PET image (c). A fusion image enabled to determine the exact location of each muscle precisely. High FDG uptakes were observed in subscapularis and deltoid muscles. The color scales indicate the pattern of FDG uptake. Red indicates maximum FDG uptake (Right shoulder at the level of humeral head, H: humeral head, G: glenoid; D: deltoid, S: subscapularis).

Figure 4. The typical muscle activity pattern observed in asymptomatic and symptomatic patients (coronal view of PET/MRI fusion images) The symptomatic patient (b) showed an increased activity of trapezius (yellow arrow) and a decreased activity of the deltoid (red arrow) compared to the asymptomatic patient (a).

Figure 5. The typical muscle activity pattern observed in asymptomatic and symptomatic patients (axial view of PET/MRI fusion images) The symptomatic patient (b) showed an increased activity in both the levator scapulae (yellow arrow) and trapezius (red arrow) compared to the asymptomatic patient (a).